27. *The* Cross Fell Inlier. By Prof. H. A. Nicholson, M.D., D.Sc., F.G.S., and J. E. Marr, Esq., M.A., Sec. G.S. (Read April 8, 1891.)

[Plate XVII.]

Contents.

§ I. Introductory.

Since the "Description of an Insulated Group of Rocks of Slate and Greenstone in Cumberland and Westmoreland, on the East side of Appleby," given by Dr. Buckland in the Transactions of the Geological Society (ser. 1, vol. iv. (1817) p. 105), a considerable number of papers have been devoted to the Lower Palæozoic rocks of that region, but as references to these are given in Mr. Whitaker's list of papers bearing upon the geology of the Lake District, published in the late Mr. Clifton Ward's memoir on "The Geology of the Northern Part of the English Lake District," it is needless to insert here an account of the bibliography of the area. An excellent summary of the work which has been achieved is given by Mr. J. G. Goodchild in a paper published in the Proceedings of the Geologists' Association for 1889*. In this paper also considerable additions are made to our knowledge of the rocks of the Inlier, and to these we shall have occasion to refer.

In the present paper, we have attempted to fix the ages of the various formations of Lower Palæozoic rocks in the Cross Fell district, to determine their organic contents, and to compare them with the corresponding rocks of other areas, rather than to give a detailed description of the general structure of the region. This latter will no doubt be done by the officers of the Geological Survey who have been engaged in mapping the district, with far fuller evidence than is at the disposal of those who have not examined the region in an exhaustive manner. Nevertheless, as a general knowledge of the structure of the region is necessary to understand the details which follow, we have drawn up a rough map which will serve as a guide until such time as the official Survey map is published, and we append a description which may serve to render the principal features intelligible.

* Proc. Geol. Assoc. vol. xi. p. 258.

§ II. General Description of the Inlier.

The Cross Fell Inlier of Lower Palæozoic rocks is marked by the occurrence of a group of pyramidal hills, stretching in a band from half a mile to a mile in width, for a distance of about 16 miles in a general N.W. to S.E. direction on the west side of the Pennine escarpment, from a little north of the village of Melmerby on the north to the south-west flanks of Roman Fell on the south. It is bounded by two great faults, which enclose it as an elongated spindle-shaped mass. The eastern fracture, which may be termed the Escarpment Fault, brings the Lower Carboniferous rocks against those of Lower Palæozoic age, whilst the western one, the Pennine Fault of the older writers, and which Mr. Goodchild terms "the Outer Pennine Fault," places the Lower Palæozoic rocks in juxtaposition with the New Red Sandstone for many miles. The lenticular inlier between these faults is furthermore broken by another great N.W. and S.E. fault, bringing Lower Ordovician rocks on the east side against the Higher Ordovician and Silurian strata of the west. This is "the Middle Pennine Fault" of Mr. Goodchild; but as a great part of the displacement here was produced at a much earlier date than that due to the other two faults, we consider it better to speak of it as the Knock Pike-Flagdaw Fault, as it is well seen between the two hills bearing those names. It is true that subsequent movement has occurred on this line along part of the course of the fault, so that at the north end of the Inlier the Lower Carboniferous rocks are included between the Ordovician and New Red Sandstone deposits, but to the south the fault is seen to pass under the Carboniferous conglomerates of Roman Fell with little or no disturbance of those rocks, and emerges again on the south-west side of the hill where the Lower Palæozoic rocks are developed.

By means of the Knock Pike-Flagdaw Fault the lenticular inlier is divided into an older eastern and a newer western portion, and it will be convenient to describe these separately, commencing with the older rocks which lie to the east of the Knock Pike-Flagdaw Fault. Unfortunately none of the rocks which occur on that side of the fault are seen to the west of it, and consequently a considerable gap occurs in the succession here, though how great it is hard to say.

§ III. Detailed Description of the Strata.

a. *The Eastern Portion of the Inlier.*—Most of the sedimentary rocks on the eastern side of the Knock Pike-Flagdaw Fault have been referred to the Skiddaw Slates, but as only few fossiliferous localities have been detected in this area, the correlation has been made to a large extent from similarity of lithological character. As the evidence furnished by these rocks is at present insufficient to establish a detailed sequence, we shall content ourselves with a very brief notice of the deposits, for it will be necessary to devote

considerable attention to the Skiddaw Slates of the more central portion of the Lake District before their minute subdivisions can be satisfactorily determined.

We believe that the oldest rocks of the Cross Fell Inlier occur in the extreme north-eastern portion of the inlier in the neighbourhood of Cuns Fell, where they are probably separated by yet another N.W. to S.E. fault from the newer rocks to the west. Here, in the course of Dry Sike and Hungrigg Sike, a series of greenish shales are seen dipping in a general south-westerly direction at a high angle. These shales furnished the obscure fossil described by one of us in the Geol. Mag. for 1869 (pl. xviii. D) as possibly of vegetable origin; but this affords no clue as to the precise age of the series. They are succeeded to the south by blacker shales and grits which bear considerable resemblance to the older Skiddaw Slates of the Lake District, and they are probably contemporaneous with these, though no fossils are recorded from them in this area, and we have found none. Similar beds are again seen farther south at Brownber, and in the streams adjoining it, and they continue over a considerable part of the ground east of the Knock Pike-Flagdaw Fault, as far south as Roman Fell. At Brownber (and in a few other places such as Murton Pike and the neighbourhood of Keisley) they have undergone great disturbance, and are penetrated by numerous quartz-veins, which are folded with the strata, causing considerable changes in the rocks, as notified by one of us at the Newcastle meeting of the British Association in 1889. Mr. Alfred Harker has kindly examined sections of these rocks for us, and has furnished us with an appendix to our paper, giving descriptions of these and other rocks of this area.

Next in order of age we would place the black shales, which occur repeated thrice, firstly in Ashlock Sike and the neighbouring tracts east of Ousby, next in Ellergill and the adjoining ground under Cross Fell, and lastly in the course of Knock Ore Gill. These strata—which we term the "Ellergill beds"—have yielded an abundant harvest of fossils, of which a list is given in Prof. Lapworth's paper on "the Geological Distribution of the Rhabdophora" *, most of them being well-known Upper Arenig forms.

At the summit of the beds referred to the Skiddaw Slates, Mr. J G. Goodchild locates his "Milburn Group," consisting, as he has pointed out, of a series of slates alternating with submarine tuffs. These are excellently displayed in Wythwaite Hole, and in the streams to the south of it, where they are also intercalated with lavas. Few fossils have yet been discovered in them, but Mr. Goodchild records *Didymograptus Murchisoni*, Bœck, and we have found *Diplograptus dentatus*, Brongn., so that the beds are probably closely related to the Ellergill Group, from which they differ in the occurrence of the volcanic material. Mr. Goodchild rightly insists upon the importance of his discovery as throwing light upon the vexed question of the relationship of the Skiddaw Slates to the volcanic

* Ann. & Mag. Nat. Hist. ser. 5, vol. iii. p. 23, sep. cop.

rocks of the Borrowdale Series, but into this question we cannot enter here. Mr. Harker has examined slides of rocks from the Milburn Group of Wythwaite and the neighbourhood, and his description will be found in Appendix I. to this paper.

Though all the bedded rocks on the eastern side of the main inlier are either shales or lavas and ashes interstratified with shales, we do get another group of volcanic rocks on the east side of the Knock Pike-Flagdaw Fault in a subsidiary inlier which lies east of the village of Melmerby, and which is separated from the main inlier by a band of Carboniferous conglomerate, a few score yards in width, abutting against the New Red Sandstone. At the south end of this small inlier a group of basic rocks, consisting of ashes and porphyritic and vesicular lavas, is separated from a group of rhyolitic rocks by the above-mentioned fault. Unfortunately, owing to the intervention of the Carboniferous beds, which are here faulted down, the relationship of the basic lavas and ashes to the shales farther south is not seen. That these basic volcanic rocks are the equivalents of the Eycott lavas was recognized by Mr. Goodchild *, and a porphyritic rock, of which a beautiful specimen from Rake Brow is preserved in the Museum of Practical Geology (London), is quite similar to one of the well-known porphyritic Eycott lavas †. Unfortunately this group of rocks is flanked by Carboniferous rocks or by faults on all sides, so that its true relationship to the other rocks of the district is not shown.

The rocks of the eastern half of the inlier are also marked by the intrusion of a considerable quantity of igneous matter, and as an examination of the intruded rocks is of importance as throwing light upon the general sequence of events in the district, we may give a brief account of their development.

The principal masses occupy the prominent ridge of Cuns Fell, and the slopes of Thack Moor. Cuns Fell is formed mainly of diabase running in a general north-east to south-westerly direction, and sending off a considerable tongue to the south. On the east side of the hill, in Ousby Dale, much felsitic rock is associated with the diabase, under such conditions that it is difficult to make out the relations of the two rocks, though on the summit of the hill a felsitic dyke is undoubtedly intrusive in the diabase. Whether or no the felsitic rocks are the newer, they probably belong to the same general period. That they were intruded before the end of Silurian times is rendered probable by the absence of cleavage in the highly baked shales below the mass, and by the existence of a schistose structure in the diabase, seen at the spring in Ousby Dale. This appears to indicate that they were intruded previously to the exertion of the pressure which has folded and cleaved the rocks, and we are inclined to believe that the masses are of the same general age as the volcanic material which forms the Borrowdale series, and are related to the volcanic outpourings of that group.

* Trans. Cumb. and Westm. Assoc. vol. ix. (1884) p. 183.

† For notes on these rocks see Appendix I.

It is noticeable in this connexion that we get several complexes of acid and basic intrusive rock in the North of England, such as might well supply material for the formation of the Ordovician lavas. The rock of Thack Moor is chiefly felsitic, and though it covers a considerable amount of ground, it is usually much decomposed at the surface. Two other felsitic masses occur to the south of this, one parallel with the Maiden Way and the other beneath Cocklock Scar.

The only other intrusive rock to which we would call special attention is a broad mica-trap dyke seen in Dry Sike, east of Melmerby, and which is of interest from the greater metamorphism produced along its margin than is usual with this class of rock in the North of England.

b. *The Western Portion of the Inlier.*—The rocks on the western side of the Knock Pike-Flagdaw Fault consist exclusively of the upper portion of the Ordovician and the lower part of the Silurian rocks, so that along the line of the above-mentioned fault the greater part of the Borrowdale series of rocks appears to have been cut out. The general strike of the rocks is N.W. and S.E., showing a marked divergence from that which characterizes the beds of the more central portions of the Lake District.

One of the principal features of this half of the Inlier is the existence of a set of N.E. to S.W. faults, which causes frequent repetition of the Upper Ordovician and Lower Silurian rocks. By these faults the west side of the Inlier is divided into a series of rectangular or triangular blocks, with a similar succession in each, and it will save space if we describe in some detail the block which exhibits the most complete section, and afterwards note similarities and discrepancies.

The rhyolitic pyramidal hill known as Dufton Pike is separated from the similar hill of Knock Pike to the north by one of the above-mentioned transverse faults, which may be spoken of as the Cosca Fault. To the N.E. of this fault, the stream called Swindale Beck runs along the south-east flank of Knock Pike to the village of Knock, and in it the following section is displayed (Pl. XVII.).

The line of the Knock Pike-Flagdaw Fault is here marked by an intrusive mass of mica-trap noticed in Appendix I. The shales on the east side of the fault, the dyke itself, and the rhyolite are all exposed in a small quarry by the side of the moorland road, N.W. of the beck. Below this a capital exposure of the rhyolite (2) which forms Knock Pike is seen in the course of the stream. It is succeeded by thin layers of rather fine, apparently unfossiliferous ashes, which seemingly pass up into the remarkable beds numbered 3 in the section. These consist of calcareous shales, with nodular masses of limestone, crowded with fossils, some of the calcareous bands being exclusively composed of the valves of *Beyrichia*. One bed of the series has been spoken of by Professors Harkness and Nicholson * as the "*Discina-corona* bed," and we propose to name

* Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 463.

the series the "*Corona* Series." The fossils contained in the series are of great interest, and altogether different from those embedded in the overlying strata. We append a list of those which have been found in the stratum in this stream :—

Beyrichia Wilckensiana, Jones.
Primitia semicircularis, Jones and Holl.
Lingula tenuigranulata, M'Coy.
Strophomena grandis, Sow.

The series (4) consists mainly of black and blue shales, often calcareous, interstratified with bands of calcareous rock which have undergone considerable disturbance. These are the well-known Dufton Shales. Their fauna is quite similar to that of the main division of the Coniston Limestone of the Lake District, so that whether we suppose that this is a more specially shaly base of the Coniston Limestone series, or an argillaceous representative of the whole of that series, we are fully persuaded that these Dufton Shales are of the age of the Coniston Limestone, and not an underlying deposit as has been previously asserted. We have found in the Dufton Shales of this stream the undermentioned fossils :—

Dicellograptus complanatus, Lapw. (?).
Diplograptus socialis, Lapw. (?).
Calymene senaria, Conr.
Cybele verrucosa, Dalm.
Illænus Bowmanni, Salt.
Phacops Brongniartii, Portl.
Remopleurides Colbii, Portl.

At the point where a tributary stream (Rundale Beck) enters Swindale from the east, the Dufton Shales are succeeded by a very calcareous deposit, numbered 5 in the section. This consists of thick beds of whitish limestone with peculiar ashy-looking green shales. Though this deposit at first sight bears far stronger resemblance to the ordinary Coniston Limestone than do the Dufton Shales, an examination of the fossils indicates clearly that it is not Coniston Limestone, but is the equivalent of a thin band at the base of the Ashgill Shales in the Lake District, which one of us has previously referred to (Quart. Journ. Geol. Soc. vol. xli. (1885) p. 487) as the "*Staurocephalus* zone." We may speak of this limestone as the "*Staurocephalus* Limestone"; in Swindale it has yielded the following fossils, which are mostly found in the interstratified calcareous green shales :—

Echinosphærites arachnoideus, Forbes.
Turrilepas.
Acidaspis.
Illænus Bowmanni, Salt.
Lichas laciniatus, Wahl.
Phacops Jukesii, Salt.
Phillipsinella parabola, Barr. (?).
Staurocephalus globiceps, Portl.

Trinucleus seticornis, His.
Orthoceras sp.

No. 6 of the section consists of blue shales with *Strophomena siluriana*, Dav., and the undermentioned fossils, all found in the corresponding Ashgill shales of the Lake District:—

Phacops mucronatus, Brongn. (?).
Orthis biforata, Schloth.
—— *elegantula*, Dalm.
—— *protensa*, Sow.
Orthisina sp.
Strophomena siluriana, Dav.

Above the Ashgill Shales, a strike-fault cuts out the Skelgill beds in the main stream, but they are found in the tributary stream, Rundale Beck. These and the deposit No. 7 of our section (the Browgill series) have been previously noticed in our paper "On the Stockdale Shales," and we have nothing to add to the description given therein. The Browgill beds pass up as usual into the blue flags with *Monograptus vomerinus* (No. 8), which appertain to the Lower Coniston (Brathay) Flags, and which represent the Wenlock Shales of other areas. These, as shown in the map and section, abut against the New Red Sandstone (No. 9) which is thrown against them by the Pennine Fault just east of the village of Knock.

In continuing our description of the rocks it will be convenient to consider the blocks into which the west side of the Inlier is divided by the cross-faults. The block to the south of the one last described is about two miles long, and is bounded on the south by the Harthwaite Fault. It is occupied by a greatly disturbed syncline having the rhyolites of Dufton Pike to the north-east, and those of Wharleycroft with a thin band of andesite (the latter probably the oldest rock seen in the western half of the Inlier) to the south-west. Between these the moory country is mainly occupied by the Dufton Shales, well exposed in Hurning Lane, Pusgill, Dufton Town Sike, Billy's Beck, and Harthwaite Beck. That they are much disturbed is shown, not only by the great crumpling which they have undergone as seen in actual section, but by the occurrence of lenticular outliers of higher strata on the S.W. slope of Dufton Pike, at Pusgill House, and near the head of Billy's Beck, and of an inlier of lower deposits in Harthwaite Beck, against the Harthwaite Fault.

The principal point to be noticed concerning the rocks of this block is the very fossiliferous character of the "*Corona*-beds" of Pusgill, of the Dufton Shales of Pusgill, Dufton Town Sike, and Billy's Beck, and of the *Staurocephalus* Limestone near the head of the latter, containing, amongst other fossils, *Staurocephalus globiceps*, Portl., and a new species of *Skenidium*.

South of the Harthwaite Fault is a triangular block apparently extending to Murton, though no exposure has been seen by us in

its southern portion. In this block comes the Keisley Limestone, to the consideration of which we must devote a few words. It is well known that the mass of limestone at Keisley, which has been frequently described, is a white or pink crystalline rock, often crowded with fossils. It occupies the southern part of Keisley Bank, and appears to be of considerable thickness, having a general southerly dip at high angles. That it is faulted against the rhyolitic series of Keisley Bank, Harthwaite, and Gregory is evident, for it rests on an ash at the east end of the block, whilst to the west it reposes on the rhyolite which forms the summit of Keisley Bank and widens out westward. This fault is also apparently one of low hade. The limestone itself shows signs of much disturbance: it contains twisted wisps of shale in places, and the occurrence of beds containing numerous *Illæni* with their convex surfaces uniformly pointed downwards indicates inversion. A list of the fossils has been previously published, but as additional forms have been found and corrections must be made in this list, we here append a fresh one:—

Halysites sp.
Lindstrœmia sp.
Primitia Maccoyii, Jones.
Ampyx tumidus, Forbes.
Cheirurus bimucronatus, Murch.
—— *cancrurus*, Salt.
—— *clavifrons*, Dalm. (?).
Cyphaspis (?) cf. *triradiatus*, Törnq.
Cyphoniscus socialis, Salt.
Cytheropsis phaseolus, His.
Homalonotus punctillosus, Törnq.
Illœnus Bowmanni, Salt.
—— cf. *conifrons*, Billings.
—— sp.
Lichas laciniatus, Wahl.
—— *laxatus*, M'Coy.
Remopleurides, cf. *longicostatus*, Portl.
Sphærexochus calvus, M'Coy.
Atrypa expansa, Lindstr. (?).
Orthis Actoniæ, Sow.
—— *porcata*, Sow.
—— *testudinaria*. Dalm.
—— *vespertilio*, Sow.
Strophomena corrugatella, Dav.
—— *deltoidea*, Conrad.
—— *expansa*, Sow.
—— *rhomboidalis*, Wilckens.
Loxonema obscura, Portl.
Orthoceras *, cf. *elongatocinctum*, Portl.

* For notes on this and other Cephalopods, see Appendix II. kindly supplied to us by A. H. Foord, Esq., F.G.S.

It has been generally recognized that this list indicates the Coniston-Limestone age of the deposit. Nevertheless, unequivocal Dufton Shales are found only one-third of a mile away in a stream between Keisley and Wharleycroft, and probably approach close to the limestone.

We believe that the Keisley Limestone may have been thrust in a north-easterly direction for some distance, and that the limestone bands have been thickened by folding during this process, whilst the shales have been to a large extent squeezed out. On the other hand, the Dufton Shales have probably had their argillaceous members largely repeated, and the limestones pulled out into lenticular masses. This seems to us the mode of explaining the great difference in the lithological characters of two deposits occurring close together and containing fossils of the same age, which accords best with the observed facts, though before finally accepting it we would advocate a closer study of similar lenticular masses of limestone which occur elsewhere, and, so far as we are aware, always in disturbed districts.

Another block occurs to the south of the one just described, and is terminated by a fault on the S.W. flank of Roman Fell, east of the farmhouse of Fell Dikes. It is also about two miles long, and is remarkable chiefly on account of the interesting development of the "*Corona*-beds" shown on the western slopes of Roman Fell, which have been noticed by Mr. Goodchild*, who rightly records the existence of Lower Bala fossils in that locality. These "*Corona*-beds" are situated above the rhyolite of the flanks of Roman Fell, and doubtless pass under the Dufton Shales of the Hilton Beck Smelt Mill. Three principal subdivisions are noticeable in Lycum Sike and the streams to the south. Resting on the rhyolite are pink ashes with *Orthis testudinaria*, Dalm., in abundance. Above these are pink shales with fine examples of *Trematis corona*, Salt., and *Lingula tenuigranulata*, M'Coy, whilst the highest beds seen, which abut against the Pennine Fault, are very calcareous ashy beds crowded with gasteropods and lamellibranchs, and containing occasional specimens of the two above-mentioned horny brachiopods.

The pink staining noticeable in these rocks is no doubt due to percolation from the overlying conglomerates.

One more block is found south of this: a cross-fault once more brings up a mass of rhyolite, which runs southward for one third of a mile, when it is cut off at Howgill Fold by the great fault which brings down the Carboniferous conglomerates as vertical beds converted into quartzite (see Appendix I.).

This block is chiefly noticeable on account of the re-appearance of the Knock Pike-Flagdaw Fault from under the conglomerate, so that a small triangular patch of leaden-grey shales appertaining to the rocks of the eastern side of the Inlier is seen on the hillside north of Howgill Fold.

The last block to be noticed occurs in the extreme north of the

* Proc. Geol. Assoc. vol. xi. (1890) pp. xcv & 263.

district, forming a great part of the subsidiary inlier which has been already noticed as furnishing representatives of the Eycott volcanic rocks. These basic rocks are faulted against the rhyolitic lavas and ashes of Shield Green, east of Melmerby. Above the highest lava is an ash apparently unfossiliferous, and the possible equivalents of the "*Corona*-beds" succeed it in the form of green ashy fossiliferous shales, which are exposed on a fell-road leading out of the Alston Moor road. These however, may belong to a somewhat lower horizon. They contain the following fossils:—

Prasopora Grayæ, Nich. & Eth. Jun.
Amphion pauper, Salt. (?).
Cyphaspis megalops, M'Coy (?).
Trinucleus Goldfussi, Barr. (?).
Orthis testudinaria, Dalm.

Above these calcareous ashes are greatly-disturbed calcareous ashy shales, which belong either to the "*Corona*-beds" or to the base of the Dufton Shales. They are seen on the high road, and have yielded:—

Prasopora Grayæ, Nich. & Eth. Jun.
Callopora pillula, Nich. & Eth. Jun.
Diplograptus sp.
Agnostus sp.
Trinucleus seticornis, His. (?).
Lingula tenuigranulata, M'Coy.
Orthis elegantula, var. (?), Dalm.
—— *plicata*, Sow.
Triplesia (?) *spiriferoides*.
Strophomena rhomboidalis, Wilckens.

Above and beyond these are representatives of the Stockdale Shales.

One more subsidiary inlier north of this shows the highest Lower Palæozoic beds seen in this district. These are the Coniston Grits which are seen dipping in a southerly direction in Limekiln Beck. A specimen of these grits has been long exhibited in the Museum of Practical Geology, and the deposit has been recognized by the officers of the Geological Survey as belonging to the Coniston Grit Series.

§ IV. Ages of the different Members of the Coniston Limestone Series.

We have already compared the earlier and later accumulations of the Cross Fell area with their equivalents in the main part of the English Lake District, and we need only add a few words concerning the rocks which lie between the rhyolites and the Stockdale Shales, for these are more fully developed here than in other parts of the North of England.

(a) Corona *Series.*—The principal variations in the lithological characters of this group were described when discussing the succession in Swindale Beck and on Roman Fell. They appear to consist essentially of calcareous ashes, with their limestones, the ashy matter becoming more abundant and coarser as we go southwards; though if the beds on the Fell Road at Melmerby actually belong to this division, this statement must be modified, for they also contain much ashy matter. It is, however, possible that they are on a somewhat lower horizon than the *Corona*-beds proper, as has been already suggested. They somewhat closely resemble the Balclatchie beds of the Girvan district, but a much larger collection of fossils than that which we have acquired must be made before a definite opinion as to their age can be offered.

We have already mentioned the fossils found in the *Corona*-beds at Swindale Beck, where the fossils are not very numerous. In other localities the yield has been far more abundant, and we append a list of the forms we have obtained from these beds :—

Monotrypa sp.	Pusgill.
Conchicolites gregarius, Nich.	Pusgill; Roman Fell.
Ateleocystites sp.	Roman Fell.
Beyrichia Wilckensiana, Jones.	Pusgill; Roman Fell.
Primitia semicircularis, Jones & Holl.	Pusgill.
Homalonotus rudis, Salt. (?).	Roman Fell.
Lingula tenuigranulata, M'Coy.	Pusgill; Roman Fell.
Orthis testudinaria, Dalm.	Roman Fell.
Trematis corona, Salt.	Pusgill; Harthwaite Beck; Roman Fell.
Ambonychia gryphus, Portl.	Pusgill; Roman Fell.
Bellerophon acutus, Sow. (?).	Roman Fell.
—— *bilobatus*, Sow.	Pusgill; Roman Fell.
Actinoceras Pusgillensis, n. sp.	Pusgill.
Cyrtoceras (?).	Roman Fell.

The gasteropods and lamellibranchs which occur so abundantly on Roman Fell, and less numerously at Pusgill, would require the attention of a specialist for their satisfactory determination. The genera *Ctenodonta* and *Pleurotomaria* appear to be represented by several species.

These *Corona*-beds seem to be older than anything which has been referred to the Coniston Limestone Series in the main Lake District. Their fauna is a very marked one, and is entirely different from that of the ordinary Coniston Limestone; and we are not aware of any similar fauna having been recorded in the British area, though it is probable that when the fossils of the Ardwell Group of the Girvan district are described they will be found to present considerable affinities to the forms which we have found in Westmorland.

Abroad, we have two calcareous deposits whose faunas are closely related to that of our *Corona*-beds, viz.: the *Beyrichia*-limestone of

Scandinavia, and the Trenton Limestone of North America. As the overlying *Trinucleus*-shales of the former region, and the Utica Slates and Hudson-River beds of the latter, can be closely paralleled with the succeeding Dufton Shales of the Cross Fell district, it seems highly probable that the *Corona*-beds may be on about the same horizon as the *Beyrichia*-limestone and the Trenton Limestone. When the beds of Wales and the Welsh border-land have been worked out in greater detail, we may expect to find a similar fauna recorded from beds situated between the Llandeilo and Bala Limestones.

(b) *Dufton Shales.*—We have already given a list of fossils from these beds as developed in Swindale. The annexed list shows those which we have obtained from other localities:—

Diplograptus truncatus, Lapw.	Hurning Lane.
Acidaspis, n. sp.	Pusgill.
Ampyx tetragonus, Ang.	Pusgill; Billy's Beck.
Calymene senaria, Conrad.	Pusgill; Hurning Lane; Dufton Town Sike.
Cybele Loveni, Linnrs.	Dufton Town Sike.
—— *verrucosa*, Dalm.	Pusgill; Dufton Town Sike.
Homalonotus bisulcatus, Salt.	Pusgill.
Lichas laxatus, M'Coy.	Pusgill.
Trinucleus concentricus, Eaton.	Pusgill.
—— *seticornis*, His.	Pusgill; Hurning Lane.
Youngia trispinosa, Nich. & Eth.	Pusgill; Hurning Lane.
Leptæna sericea, Dalm.	Pusgill; Hurning Lane.
—— *transversalis*, Wahl.	Hilton Beck.
Lingula ovata, M'Coy.	Hilton Beck.
Orthis biforata, Schloth.	Dufton Town Sike.
—— *testudinaria*, Dalm.	Pusgill; Harthwaite Beck.
—— *vespertilio*, Sow.	Dufton Town Sike.
Strophomena expansa, Sow.	Harthwaite Beck.

Most of these fossils are common in the Coniston Limestone, the Bala Limestone, and the *Trinucleus*-shales of Sweden, and there is no doubt that the Dufton Shales, if not actual representatives of the Coniston Limestone, are far more closely allied to it than to the underlying "*Corona*-beds" with which they have hitherto been associated.

(c) *Keisley Limestone.*—As to the general age of this there is no doubt. The group of fossils is essentially that of the Coniston Limestone. At the same time, the occurrence of some forms which have not been found nearer than the Chair of Kildare may indicate that we have here a fossil zone which is not represented by fossiliferous beds in the central part of the Lake District.

(d) Staurocephalus-*Limestone*, and (e) *Ashgill Shales.*—As these beds are quite similar to the corresponding strata of the Lake District, it is unnecessary to say anything further about them.

§ V. Conclusion.

Although the rocks of this district are so greatly disturbed, an examination of the richly fossiliferous deposits indicates beyond doubt, in most cases, the original order of succession of the strata. We find that, though in general the deposits are similar to those of the adjoining Lake District, there are important variations in detail, especially with regard to the Coniston Limestone group, and we feel convinced that a study of this Cross Fell area is absolutely necessary to the right understanding of the sequence of events which marks the history of the Lower Palæozoic rocks of the North of England.

EXPLANATION OF PLATE XVII.

Fig. 1. Map of the Cross Fell Inlier on the scale of one inch to a mile.
Fig. 2. A portion of the same on the scale of two inches to a mile.
Fig. 3. Section in Swindale Beck on the scale of six inches to a mile.

APPENDIX I.—Petrological Notes *on* Rocks *from the* Cross Fell Inlier. By Alfred Harker, Esq., M.A., F.G.S., Fellow of St. John's College, Cambridge.

1. Skiddaw Slates.

It will not be practicable here to deal with more than the leading rock-types of a rather complex area. Further, as my own acquaintance with the district is slight, and most of the specimens studied were collected by Prof. Nicholson and Mr. Marr, these notes will not aim at being more than merely descriptive, and must be regarded as only supplementary to the field-work embodied in the foregoing paper.

The general character of the Skiddaw Slates is known from the descriptions of numerous writers on the Lake District. In particular, the occurrence in the group of subsidiary volcanic rocks has been indicated on the Geological Survey maps and in Mr. Clifton Ward's Memoir. It will be sufficient here to notice certain modifications of the slate-rocks due to metamorphic agencies, and to describe two or three examples from the volcanic portions of the group.

The evidences of dynamo-metamorphism in the Skiddaw Slates of Brownber, &c., have already been pointed out by Mr. Marr. Judging from his specimens, the rocks thus modified still part along the surfaces of original deposition, as marked out by alternations of purely argillaceous and more gritty bands; but on the wavy

divisional surfaces thus obtained are seen minute wrinkles having the same direction as the broader undulations, while a cross-section shows that these small folds have for the most part passed into little parallel faults making a high angle with the bent surfaces of lamination. In a thin section [913] * the gradual passage of the minute folds into reversed faults is beautifully exhibited, and many more are brought to light than can be detected in a hand-specimen. There are sometimes as many as two or three hundred in an inch, or even more. All the appearances recall the microstructure of the "gnarled" beds near Amlwch, &c., in Anglesey †. In the specimens from Brownber the wrinkled lamination-surfaces present a dark and glossy aspect, which the microscope shows to be due to the development of a chloritic or micaceous mineral in the rock.

The chief secondary product is a flaky mineral showing the strong cleavage of the micas, chlorites, &c., and giving sensibly straight extinction. The flakes vary from pale greenish-yellow to colourless, the absorption being stronger for vibrations parallel to the cleavage-traces than for those perpendicular. The least axis of the ellipsoid of optic elasticity is at right angles to the cleavage. The birefringence, roughly estimated by comparison of the polarization-tints with those of quartz, is usually about 0·012, but sometimes as much as 0·014. These figures correspond in the table of Lévy and Lacroix to clintonite and delessite respectively. Further, there are in places small colourless flakes giving much higher double refraction and agreeing in character with muscovite. It is evident that, besides the dominant chloritic mineral, a micaceous one is also present, and the appearances suggest that the latter represents a further stage of metamorphism than the former. The brilliantly polarizing mica appears only on planes of actual discontinuous movement in the slate or in little isolated flakes in the gritty bands, and these are evidently the places where the mechanical stresses developed would reach a maximum. It appears that the discontinuous movement in the mass of the rock has been effected after the production of the chloritic mineral which almost completely pseudomorphs the original argillaceous material, and the flakes, except where they have been dragged along in the slipping, lie obliquely to the little faults.

The gritty bands in the rock sometimes retain their clastic appearance, but in some cases their appearance suggests recrystallization *in situ*. The constituents are quartz and felspar, among which occur sparsely flakes of the chloritic mineral and the colourless mica. The quartz often shows something of the "undulose" or "spectral" polarization indicative of a condition of strain. The felspar is frequently twinned, and seems to embrace both orthoclase and an acid plagioclase. The perfectly pellucid character of the little crystal-grains and, in some places, the fashion in which they

* The numbers in square brackets refer to the microscopic rock-sections in the collections of the Woodwardian Museum, Cambridge.

† See Rep. Brit. Assoc. for 1885, pp. 839, 840.

fit into one another can scarcely be explained except on the supposition that they have been recrystallized under the influence of mechanically produced stress.

These metamorphosed slates of Brownber contain pseudomorphs of limonite, about a tenth of an inch in diameter, evidently replacing cubes of pyrites. The pyrites has been formed *in situ*, for occasional grains of quartz, &c. are enclosed. Moreover, its decomposition has been subsequent to the crushing of the rock, for the cubes are not sensibly distorted. Indeed, the movement of the rock about the pyrites-crystals has been such as to leave vacant spaces, afterwards filled by secondary quartz. This quartz has a rather fibrous structure, and is arranged at right angles to the faces of the pyrites cubes. It is found only on those parts of the cubes where the pressure would be relieved by the flowing movement of the rock-mass, and the phenomena are precisely similar to those which I have elsewhere described as common in pyritous slates *.

As to modifications produced by thermal agency, a few words will suffice. The Skiddaw Slates show some degree of metamorphism near their contact with the Cuns Fell diabase. A slice in Prof. Nicholson's collection is a well-laminated rock, in which numerous minute grains of clastic quartz are mingled with the argillaceous material. It is marked throughout with irregularly ovoid spots, one-fiftieth to one-hundredth of an inch in diameter. Along certain bands these spots are merely clear patches due to the dusty (carbonaceous ?) matter having been expelled, to collect just beyond the margin. In other bands the clear spots thus left behave optically in a different way from the surrounding ground, being mostly dark between crossed nicols. The quartz-sand occurs indifferently inside and outside the spots, and the grains have lost nothing of their sharpness of outline.

Near the large lamprophyre dyke in Dry Sike, again, the Skiddaw Slates appear highly metamorphosed, being converted into a very compact black rock with a certain degree of lustre and a conchoidal fracture, like some varieties of *hornfels*. A slice of this rock, which is rather a microscopic grit than a true slate, shows as the chief metamorphic product a rather obscure chloritic mineral. The numerous minute quartz-grains retain their angular outline [912].

Among the lavas occurring in the Skiddaw Slate group, an interesting rock was collected by Mr. Marr in the stream north-west of Master Sike [920]. It is an andesite consisting essentially of an isotropic base crowded with very minute felspar-microliths. These only occasionally show any parallel arrangement, although a streaky fluxion-structure is seen in the mass as a whole. There are a few small porphyritic felspars with good outlines. No augite is recognizable, though its former presence is probably indicated by the pale delessite-like substance filling some small ovoid vesicles in the rock. The interesting point is a vesicle about a twelfth of an inch in length, with a complex structure recalling in some respects

* Geol. Mag. (1889) pp. 396, 397.

that of the *lithophysæ* in some acid lavas. There are, however, novel peculiarities. The cavity has been at one time lined with a thin coating of a pale-green chloritoid mineral, which for brevity may be called delessite. It has a fibrous structure, with partial fan-like grouping, roughly perpendicular to the surface on which it was deposited. From this surface it has for the most part broken away, so as to divide the cavity by partition-walls, not however continuous. A second coating of the same material has also to some extent become detached, and with it portions of the andesitic matrix itself. Subsequently crowds of minute but perfectly-formed felspar prisms have been formed, clustering especially, with a tendency to perpendicular growth, on the detached fragments of andesite where these were not protected by a coating of delessite. Finally, all the remaining space has been occupied by clear crystalline quartz. The little felspar-crystals are clear, and invariably have twin-lamellation. The birefringence is very near that of quartz, and sections nearly perpendicular to the twin-plane give extinction-angles up to about 18°. These characters do not distinguish between albite and andesine. The curious feature is the clear evidence that the felspar-crystals were formed within the vesicle subsequently to the deposition of the usual coating of green decomposition-product.

A few days after the preceding paragraph was written, Mr. W. Maynard Hutchings informed me of his independent discovery of felspar within the vesicles of some Lake District rocks, and the specimen which he kindly lent me showed relations in some respects analogous to those briefly described above. The subject is one which will no doubt repay further investigation, and we may expect that Mr. Hutchings's work will throw light on this curious mode of occurrence of felspar.

The rock exposed in Wythwaite Hole seems to be a contemporaneous lava of more crystalline type (dolerite), but is too deeply altered for minute study. Besides evident spherical vesicles, there are seen under the microscope little irregular spaces occupied by quartz-mosaic, but the manner in which the lath-shaped felspars project into these renders it doubtful whether the spaces were originally vacant [1321].

A very singular rock occurs on Wythwaite Top. To the eye, it appears a coarse ash or fine breccia. Besides minute glistening felspar-crystals in the general mass, there are little fragments which themselves enclose felspars. In a slice [1322] the fragmental character is scarcely apparent. Idiomorphic felspars are scattered through the rock, showing twin-striation of the ordinary kind, occasionally crossed by pericline-lamellæ. Rarely there is a grain of quartz of clastic appearance, or a green pseudomorph which seems to come from a rhombic pyroxene. The general ground of the rock appears in ordinary light partly turbid, partly clear, the two occurring in intermingled irregular patches. The turbid portion presents a finely "felsitic" appearance, but the clear ground consists almost entirely of a mass of perfectly pellucid small crystals

and grains of felspar. Most of these have twin-lamellation and often an imperfect prismatic shape, so far as their crowded occurrence permits. Others are only once twinned, and some shapeless simple grains, with a tendency to occur interstitially, are perhaps quartz. The structure of these patches and the limpid nature of the felspars are characteristic of metamorphic rocks, and point unmistakably to recrystallization of the rock *in situ*. Any doubt is removed by an examination of the porphyritically disposed felspars already noticed. These are frequently bent and broken, and there seems to be some secondary twin-lamellation induced by stress. The most striking feature, however, is the replacement of the original turbid crystals by new felspar-substance exactly similar to the little striated felspars in the general ground of the rock. Some of the original crystals do not show this alteration; others are partially changed; and others, again, are totally converted into clear crystalline aggregates, preserving only the outline of the crystal from which they have been formed. The newly-formed triclinic felspars, cut perpendicular to the twin-plane, give a maximum extinction-angle of about 18°. This agrees with albite, though a certain variety of andesine would give the same value. A curious point about the dynamo-metamorphism is the seemingly capricious manner in which it has affected the mass of the rock.

As an example of the ordinary fine ashes of the Skiddaw Slate group, a rock from Burney was sliced [921]. It shows plenty of felspar-crystals, or more frequently broken portions of crystals, some showing twin-lamellation, others not. The general mass of the rock has probably been a felspathic dust, but now contains a quantity of quartz and calcite, besides pyrites and yellow opaque spots of ferruginous matter. Of these the quartz seems to be the latest-formed, occurring in little continuous patches of ragged outline and enclosing other decomposition-products. Little, if any, of this mineral is in original grains, and there is no indication of detrital material mingled with the volcanic.

The grits in this group of rocks are derived from the disintegration of igneous rocks of more than one kind. A specimen from the north side of Mudgill Sike [964] was found to consist essentially of grains of quartz, unrolled crystals of plagioclase, and rather rounded fragments of a microlithic andesite. A few rolled granules of decomposing augite occur, and a fragment of quartz-porphyry showing a microgranitic groundmass and a portion of a porphyritic quartz. The quartz-grains, which are the most abundant constituent, are mostly subangular to rounded, but some of the smaller ones are quite angular. They are for the most part clear, though some contain rows of fluid-pores. The felspars are sometimes penetrated by apatite needles, and resemble those which occur porphyritically in many andesites. In sections perpendicular to the albite twin-plane the extinction-angles range up to 13° or 14°. The rock contains a little calcite, partly in pseudomorphs after felspar. Other authigenetic constituents are pyrites and a little quartz, the latter sometimes forming narrow veinlets.

2. Basic Lavas of Melmerby.

The porphyritic lava of Melmerby presents in hand-specimens a striking appearance. Glassy-looking felspars, up to half an inch in length, showing to the eye both Carlsbad and albite twinning, are embedded in a dark compact ground. One is strongly reminded of the well-known porphyritic lavas of Eycott Hill, and closer examination leaves no doubt as to the identity of the rocks from the two localities. The type is a rather unusual one, the composition being decidedly more basic than that of normal andesites, while on the other hand olivine is wanting, being in a sense represented by a rhombic pyroxene with abundance of free iron-ore. Perhaps the best name would be hypersthene-basalt.

In specimens from Eycott, Mr. J. Hughes * found the silica-percentages 53·30, 52·60, and 51·10; Mr. T. Cooksey † found 53·40 and 52·73. The Melmerby rock is so similar that an analysis is scarcely necessary. A determination of its specific gravity gave 2·753, the figure for the Eycott rock being 2·754 (Cooksey, *loc. cit.*).

The porphyritic felspars are often grouped in such a fashion as to interfere with one another's growth, while always presenting crystal-faces to the surrounding matrix. They are on the border-land between labradorite and bytownite, being apparently a little more basic than the type hafnefjordite, Ab_1An_3. In sections perpendicular to the lamellæ of albite-twinning the extinction-angles range up to 37°, reckoned from the twin-line. This is for the greater part of the crystal: the border gives a rather lower angle. As regards habit, extinction-angles, zonary structure, inclusions, &c., Mr. Teall's ‡ accurate description of the Eycott felspars may stand equally well for these.

The chief feature of the groundmass is the plentiful occurrence of a rhombic pyroxene, almost often to the exclusion of augite. This is also the case in the Eycott rock, as was first pointed out by Prof. Bonney (*loc. cit.*). The mineral is, however, invariably replaced by bright-green fibrous bastite. The strong colour and pleochroism of this substance, with the occurrence in it of abundant secondary iron-ore, point to a ferriferous variety of pyroxene, hypersthene rather than enstatite. The groundmass of the rock contains plenty of magnetite. In tolerably fresh specimens [1250, 1251] this shows the outlines of octahedral crystals, and is clearly original; but in more weathered examples the whole mass of the rock is rendered almost opaque by the separation of secondary magnetite with other decomposition-products. The felspars of the groundmass are probably not very dissimilar in nature to the larger felspars; they occur in small slender prisms, but always show albite-lamellation, and do not sink to mere microliths. There appears to have been some augite, in small granules now represented by calcite and a pale almost isotropic material; and there

* J. Clifton Ward, Monthly Microscop. Journ. (1877) vol. xvii. p. 246.
† T. G. Bonney, Geol. Mag. (1885) p. 80.
‡ 'Brit. Petrogr.' (1888) pp. 225–227.

must have been a considerable amount of unindividualized base. The general characters of the groundmass bring the rock nearer to the normal basalts than to the andesites.

3. Rhyolitic Rocks.

The normal rhyolitic rocks do not differ in any marked way from those underlying and intercalated in the Coniston Limestone of the Lake District. Both lavas and ashes are found. The lavas are not conspicuously porphyritic, though little felspars are often scattered through the rock: these, as usual, are plagioclase. The rocks show a generally compact appearance, light grey or cream-coloured when not stained by iron oxide. The groundmass has probably been to a great extent glassy, when the rocks were fresh, but this has not always been the case. A rock from the beck north of Keisley, for instance, has a microlithic character.

The specimen just mentioned [919] shows a kind of flow-brecciation, which I believe is not an uncommon feature. Very similar appearances are seen in some of the Caernarvonshire rhyolites. In the Keisley rock the fragments of the original lava, probably the broken-up crust of a *coulée*, are divided by a matrix, or system of irregular branching veins, which makes up quite half of the whole mass. This matrix seems at first sight to consist of rather finely crystalline quartz; but closer scrutiny serves to detect in some of the clear grains the rectangular outline and the twinning of felspar. This matrix, therefore, must be regarded not as an infilling of vein-quartz entirely subsequent to the formation of the rock, but rather as an inflowing of the highly acid mother-liquor from which the earlier portion of the rock was formed, and so as representing only the latest phase in the consolidation of the lava. In one place the matrix contains an amygdaloidal cavity, some twentieth of an inch in length, on the border of which crystallization is rather better developed, and the felspar-twinning of some of the crystal-grains is well seen. The slide shows some genuine vein-quartz which occupies little cracks traversing the microlithic fragments and their matrix alike, and the contrast of these with the latter can be easily observed.

Other rocks in the neighbourhood of Keisley are ashes, and one from Harthwaite Beck is a vesicular andesite with finely microlithic ground [1283]. It is noteworthy that here, as elsewhere among our Ordovician lavas, a vesicular structure is much rarer in the rhyolites than in the andesites.

A well-marked type of acid lava is exemplified by a specimen from Gregory Hill near Dufton, "the second rhyolite below the Keisley Limestone." A slide of this rock in Prof. Nicholson's collection [L. D. 28] shows a groundmass enclosing a few scattered felspars, which, when not too much decomposed, give faint indications of twin-striation. The ground has in natural light a mottled appearance owing to numerous clear spots, with a tendency to rounded outline, from which some dusty material seems to have

been eliminated. These spots consist of crowds of exceedingly fine microliths, doubtless of felspar, embedded in quartz, which in each spot behaves as a single crystal. The darker portion of the ground has similar microliths, but in a matrix which remains dark between crossed nicols. The spots, about one-hundredth of an inch in diameter, make up most of the rock, which has a superficial resemblance to certain "spotted slates." In describing a somewhat similar structure in the rhyolites of Penmaenbach *, I was inclined to regard the crystallization of the quartz in the spots as an original character, but the point is not quite clear.

The rhyolitic rocks exposed in Swindale Beck show some remarkable features. The dominant type, as seen in the field and in hand-specimens, is a compact pale-salmon or cream-coloured rock, in which darker grey patches, with sharply defined outlines, indicate included fragments. Under the microscope [822] the greater part of the groundmass is obscure, owing to secondary quartz. There is a well-marked, rather wavy parallel structure which might be the lamination of a fine ash, though it is more like the flow-structure of a lava; and the scattered felspar-crystals, rarely broken, lie with their long axes in the same direction. There are numerous little included fragments of a microlithic andesite, and these would naturally cause the rock to be regarded as an ash, were it not for a special structure well shown in the slide. This is the occurrence of discontinuous bands or narrow streaks, following the flow-lines in the rock, in which a thoroughly crystalline texture is developed. These crystalline streaks consist of clear felspar, often in lath-shaped crystals showing twin-striation, some quartz, and, between the felspars, little areas of pale decomposition-products, such as usually indicate vanished augite. This Swindale Beck rock is, therefore, a "eutaxitic" lava, which has caught up fragments of the rocks, andesitic and others, through which it has broken out. A eutaxitic structure, though of rather different type, has been noticed in certain Caernarvonshire rhyolites (*op. cit.* pp. 21, 22).

4. Acid Intrusive Rocks and Transitional Types.

The acid intrusive rocks of the district are quartz-porphyries, which do not call for much remark. The best known is the so-called "Dufton granite," which forms a small boss to the west of Dufton Pike. It is a rock of red colour, resembling some of the "granite-porphyries" in general appearance. Besides abundant red felspars, it shows quartz-grains about a quarter of an inch long, and small flakes of black mica. Scattered through the rock are hexagonal plates of white mica, up to an inch in diameter; while occasionally is seen a colourless felspar-crystal, perhaps an inch and a half long, with the markedly tabular habit, the glassy lustre, and the longitudinal fissures (following an orthopinacoidal cleavage) of sanidine. These crystals are twinned on the Carlsbad law, and recall similar ones in a dyke on Stakeley Moor, south of the Shap

* 'Bala Volc. Series of Caernarv.' (1889) pp. 22, 23.

Fell granite*. The whiter and finer-grained rock which crops out just to the eastward of the foregoing is probably only a marginal modification of the main mass. Here the plates of white mica are rarer, and the most striking feature is the occurrence of long narrow blade-like crystals of dark mica, precisely like some found on the margin of the Shap Fell granite and in the dyke on Potter Fell, which seems to be connected with that mass†.

A slide [842] of this Dufton Pike rock shows plenty of porphyritic quartz, in clear idiomorphic crystals with only a few glass-cavities or small inclusions of groundmass. Among the porphyritic felspars, a plagioclase with Carlsbad-, albite-, and pericline-twinning predominates. The light mica is perfectly clear and colourless, the dark decomposing with a green colour. Rarely the two are intergrown. Both micas recur in small flakes with a rough parallel disposition, and these must be regarded as part of the groundmass. An occasional hexagonal prism of apatite is seen. The ground of felspar and quartz is of the microcrystalline or "micrographite" type.

A specimen from a dyke north-west of Cuns Fell differs somewhat from the preceding, especially in the absence of white mica, and probably represents the usual type of the district [918]. The porphyritic crystals of quartz have their edges rather rounded, and are sometimes broken, but the fragments are not far separated. A flake of dark mica is sometimes enclosed in the quartz, as well as in the porphyritic felspars.

On the hillside north-west of the "Spring" in Ousby Dale the rock shows some remarkable modifications, which can be referred only to intense dynamic metamorphism. In the field it shows only a slightly different appearance from other examples of these quartz-felspar-porphyries, except that it has a general yellow iron-stained colour. A section, however, shows that a large part of the rock consists of colourless mica [1319]. The porphyritic felspars without losing their form are completely replaced by minute scales of this mineral, the scales in any one pseudomorph having a very general, though not uniform, orientation parallel to the length of the original felspar-crystal. Similar scales of mica occur in great quantity in the general mass of the rock, together with large flakes, which are rather ragged and wavy, and do not give very precise extinction between crossed nicols. The rounded and corroded porphyritic crystals of quartz are only occasionally cracked and broken. Dark mica is absent, but is perhaps represented by the larger flakes of colourless mica, each of which encloses a shapeless patch of limonite. Little flocculent patches of yellow ferruginous matter occur also in the groundmass. Except for these and the minute scales of mica, the ground consists of a clear microcrystalline mass of quartz and felspar, without trace of crystal outlines, and highly suggestive of recrystallization *in situ*. It is not easy to

* See p. 288 of this volume.
† See p. 277 of this volume.

distinguish the felspar from the quartz; the great majority of the grains are simple, but here and there one shows twin-striation. It will be noticed below that the diabase near this locality gives evidence of great crushing.

The large igneous mass on Thack Moor and the intrusions in Ousby Dale, apparently offshoots of it, belong to the same general type as the Dufton intrusive rock, but lack white mica. In all these rocks the closeness of the porphyritic crystals, obscuring the groundmass, gives a very crystalline appearance in the field or in hand-specimens.

Certain intrusive rocks, such as the large mass to the south of Cocklock Scar and some dykes, *e. g.* at Maiden Way in Ardale Beck, show a considerable departure from the foregoing and an approach to the characters of the lamprophyres described below. In hand-specimens they have a less crystalline appearance than the quartz-porphyries, and quartz is not recognized. The general aspect is that of some so-called porphyrites, the colour being brown with little stained felspar-crystals and facets of dark mica and augite. The slices [916, 922] bear out the idea of a transition to the lamprophyre type. Besides the greater abundance of dark mica, mostly undergoing a greenish alteration, we notice the coming in of abundant apatite and magnetite, and especially of augite in perfectly formed crystals, now completely pseudomorphed. The groundmass of these rocks is much decomposed, and it is difficult to decide whether any part of the free silica is original.

5. The Lamprophyres.

It would not be easy, and perhaps not very profitable, to attempt any such division of the "mica-traps" of the North of England as that between minettes and kersantites. A distinction founded on the crystallographic systems of the felspars is more futile than usual in this case, since those minerals are usually too far destroyed for recognition. Analysis might, of course, show the relative proportions of potash and soda present; but as this does not seem to bear any relation to the percentage of silica, &c.*, the character of the original felspar in any case would import little as regards the essential nature of the rock. The family-name "lamprophyre" is therefore sufficiently precise. In some of the rocks, as in Rosenbusch's "vosgesite," idiomorphic augite accompanies or to some extent takes the place of mica.

Like most lamprophyres, these rocks are very prone to decomposition by weathering agents, and are often impregnated with secondary carbonates. The freshest examples have a dark grey ground plentifully spangled with flakes of dark brown or nearly black mica, sometimes as much as an inch in diameter, but usually much less. In more altered specimens the mica takes a deep brown colour, with

* See Bonney and Houghton, Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 165.

submetallic lustre, and the groundmass, also stained with brown, has a dull appearance. Visible porphyritic felspars are found, but only very sparingly. The boundaries are often rounded, as if by magmatic corrosion. Occasionally a crystal of orthoclase shows a quite glassy lustre, but the felspars are usually dull and semi-opaque. Certain rocks, such as the large dyke in Dry Sike and the boss-like mass in Swindale, enclose grains of quartz of considerable size, the boundary rounded, or rarely with indications of the dihexahedral form. The grains are commonly surrounded by a thin coating of a dark green substance.

Included fragments of partially vitrified grit, &c., are found in the large Swindale boss. Vesicles, usually filled by calcite, also occur.

The mica of these rocks is a brown biotite in tabular crystals more or less regularly bounded in the usual pseudo-hexagonal fashion. The plane of the optic axes is perpendicular to the basal cleavage and parallel to the clinopinacoid. The bisectrix makes a very sensible angle (3° or 4°) with the normal to the basal cleavage, so that in cross-sections of the flakes the frequent twin-lamellation parallel to the base is easily detected. Indeed, owing to the pleochroism, this can be seen with a single nicol. Juxtaposition-twins parallel to the prism-plane * are also common. In almost every case the deep brown colour characteristic of biotite in most rocks is here confined to the border of each flake, the interior being much paler, or, indeed, for vibrations parallel to the a-axis, sensibly colourless. Whether this is an original zonary structure or a result of internal bleaching is not quite clear. Rosenbusch † apparently takes the former view for the mica of lamprophyres generally. It is noticeable that, although in cross-sections of flakes the border is usually very sharply defined, basal sections show a more gradual passage from dark to pale. Streaks of darker colour, following the basal cleavage-direction, are occasionally seen passing through the pale interior, and this seems rather to favour the idea of secondary bleaching. Much rarer than the dark border is a dark nucleus, always sharply defined by crystallographic planes, with a paler margin [915]. The dark and pale mica-substances in these rocks possess very different powers of birefringence. Rough measurements gave the figures 0·06 and 0·04, which, according to Lévy and Lacroix, correspond to brown biotite and colourless meroxene respectively.

Resorption-phenomena, with a separation of iron ore, are sometimes seen on the edge of a flake [914]. Again, owing to mechanical forces, the flakes have in some cases yielded along "gliding-planes," as in the artificial twin-lamellæ produced in calcite, &c. The gliding-planes do not coincide with the basal cleavage [914]. The mica occasionally encloses grains of magnetite, or is penetrated by slender hexagonal prisms of apatite. Again, the edge of a flake

* See Lévy & Lacroix, 'Minéraux des Roches' (1888), p. 239, fig. 137.
† 'Mikr. Physiogr. d. mass. Gest.' 2nd ed. (1887) p. 310.

sometimes shows numerous very minute needles (? rutile) arranged along the basal cleavage, parallel to the sides of the hexagon [915]. The most characteristic inclusions, however, are very minute crystals, probably of zircon, which are invariably surrounded by strongly pleochroic halos. These halos are very conspicuous, reproducing in the pale interior of the flakes the dark colour of the brown border. A common decomposition-product of the mica is calcite, or possibly dolomite, often forming lenticles or plates along cleavage-planes [445] *.

In addition to mica, some at least of the rocks, such as those of Dry Sike, have contained augite. The mineral is completely destroyed, but the pseudomorphs show the characteristic octagonal cross-section [915]. Original magnetite is not plentiful in our specimens. Most of the slides contain little crystals of pyrites, which moulds the biotite, and is perhaps a secondary mineral. The porphyritic felspars, when recognizable, are seen to be orthoclase and a plagioclase with rather low extinction-angles; but most of the felspars are deeply altered, and some are entirely replaced by calcite [914].

The quartz-grains, already alluded to, present in section an ovoid outline, or, more rarely, rounded crystal-forms [915]. The bordering ring is seen to consist of minute crystals of fibrous hornblende, pale green in a slice. These are partly moulded by the quartz, while, on the other hand, they are not distinctly separated from the mass of the rock. The appearances suggest a reaction between the quartz-grains and a corroding magma, and recall the primary quartz-grains with a coating of augite-granules described by Iddings † in certain basalts.

The groundmass of these lamprophyric rocks is for the most part too much decomposed for precise study. It has probably been microcrystalline throughout. In some cases the mica seems to belong to two generations, of which the later, in smaller flakes, forms part of the ground [445, 446 *a*]. The bulk of the ground has consisted of felspars, which sometimes sank almost to microlithic dimensions [915]. The most abundant decomposition-products are calcite and quartz. Where these occur collected in distinct patches, the quartz is often idiomorphic and moulded by the calcite.

6. Basic Intrusive Rocks.

The chief intrusive rocks of basic character in the district are the diabases of Cuns Fell. These show considerable variations in texture. In the coarse-grained type it is easy to recognize the rectangular crystals of striated felspar and the dark green cleavage-faces of augite, or, again, black lustrous plates of hornblende. As will appear, this last mineral is not an original constituent. In the

* This is the slide figured in Teall's 'Brit. Petrogr.' pl. xxxii. fig. 2.

† Amer. Journ. Sci. (3) vol. xxxvi. (1888) p. 208; Bull. U.S. Geol. Surv. (1890) No. 66.

specimens of finer grain the individual minerals are scarcely to be detected by the unaided eye.

In mineralogical constitution the Cuns Fell diabases present no special peculiarities. Apatite prisms occur plentifully, though only locally [924]. Crystals and rods of magnetite are always present, but ilmenite is not found. The bulk of the rocks, now considerably decomposed, has been built of felspar and augite, the former in idiomorphic crystals, the latter mostly in ophitic or semi-ophitic plates. The Cuns Fell rock has been termed a gabbro, but its structure is that of a typical diabase, with even an occasional approach to the doleritic type in the development of a few shapeless felspars of later consolidation. The ordinary felspars show albite- and pericline-twinning, and, so far as can be judged from their extinction-angles in rock-slices, may be referred to the border-land between andesine and labradorite. The augite, when unaltered, is colourless in sections, but this mineral is frequently quite destroyed, the common decomposition-products being pale-green delessite, clear quartz, calcite, and opaque dust (kaolin?). It is, however, frequently replaced by hornblende; sometimes pale greenish-yellow with a fibrous structure and inclusions of secondary magnetite, but more usually clear yellow-brown and pleochroic with a compact structure and good prismatic cleavage. There can be no doubt that this mineral is derived from the augite: the process of conversion, beginning at the margin and along cleavage-cracks, is seen in various stages [925]. The hornblende, as in some other rocks of this kind, gives rather high extinction-angles ($c\,\gamma$ = about 20°); and it is to be noticed that, in an augite-plate partly transformed into hornblende, the extinctions for the two minerals are, as usual, on the same side of the vertical axis.

Another common feature of these diabases is the occurrence of a fringe of colourless hornblende growing in crystallographic relation with the crystal-plates, but outside them, and clearly formed at the expense of other minerals, to which it presents a very ragged edge. Such fringes surround not only the uralitic hornblende, but also patches of delessite which are evidently the relics of vanished augite. The order of the several changes indicated is therefore:—(i.) partial or total replacement of augite by hornblende, the uralitic hornblende being perhaps a stage in the conversion to the compact; (ii.) growth of colourless hornblende-fringes about both hornblende and augite, this proceeding concurrently with alterations in the felspar, &c.; (iii.) conversion of much of the remaining augite into delessite and other weathering-products.

The hornblendic rocks examined are from the west and north-west sides of Cuns Fell. On the south-east side, near its junction with the Skiddaw Slates, the diabase takes on a finer grain, and, in particular, the felspars occur in long narrow prisms only once or twice twinned on the albite law, without, however, any marked parallelism of disposition [928]. At Dale Beck the diabase has a very crushed schistose appearance, and a slice shows that it consists mainly of calcite and delessite [926]. Another specimen

from this neighbourhood (marked 'Spring' on the six-inch map) has in addition a quantity of finely crystalline to cryptocrystalline silica, sometimes with a spherulitic structure [1320]. In the field this rock presents a singular appearance owing to the numerous parallel narrow veins of calcite which traverse its dark mass.

A specimen of diabase from a dyke in Rake Beck differs in some respects from the Cuns Fell rocks. The felspar seems to approach typical labradorite, and encloses occasional crystals of light-brown sphene [923].

At Deep Slack Wood, close to the exposure of the basic lavas of Melmerby, occurs a fresh-looking, finely crystalline dolerite, very different from the neighbouring rocks. It consists largely of little lath-shaped striated felspars, besides a few larger individuals with broader lamellæ and an occasional shapeless felspar with strong zonary structure, of the kind so characteristic of doleritic rocks [1323]. The augite forms ophitic plates each enclosing many of the small felspars; magnetite occurs interstitially among the felspars in some abundance. The felspars are always quite clear; much of the augite is fresh, but part is replaced by brown and green decomposition-products, and a similar green substance fills the few scattered vesicles. The rock is unlike any known Ordovician lava or intrusion in the district, and suggests a dyke of much later age, post-Carboniferous or even perhaps Tertiary.

7. Quartzite of Roman Fell.

An interesting modification of the Carboniferous sandstone is represented by some of Mr. Marr's specimens collected on Roman Fell. The sandstone here has been locally converted into a compact vitreous-looking rock by the deposition of secondary quartz.

Under the microscope [911] the rock exhibits all the characters of a quartzite such as those of Hartshill and the Stiperstones *. The original grains are almost all well rolled. Quartz largely predominates, mostly with a very dusky appearance due to crowds of inclusions, often ranged in parallel lines. A few of the quartz-grains are composite. In much less quantity occur weathered felspar-fragments and little rounded pieces of a microlithic andesite. The interstitial quartz occurs entirely as a "secondary enlargement," easily distinguished from the original grains, with which it is in crystalline continuity, by its clear appearance. More rarely the felspar grains show a similar secondary growth, a phenomenon observed elsewhere by Van Hise and others. It occurs both on orthoclase and plagioclase-fragments.

* Compare, *e. g.*, the Lickey quartzite figured in Mr. Teall's 'Brit. Petrogr.' plates xlv., xlvi.

APPENDIX II.—*On some* Cephalopoda *from the* Cross Fell Inlier.

By A. H. Foord, Esq., F.G.S.

1. Orthoceras, *cf.* elongatocinctum, Portlock.

Portlock, 'Geology of Londonderry,' (1843) p. 372, pl. xxvii. figs. 2 *a*, 2 *b*. Blake, 'British Fossil Cephalopoda,' pt. i. (1882) p. 119, pl. xiii. figs. 7, 8, 8 *a*.

Description. An elongated, cylindrical species with a very slow rate of increase: the septa, as seen in fragments, distant from each other rather less than one-third the diameter of the shell. The siphuncle nearly central. The test ornamented with regular, transverse, thread-like striæ, which do not appear to undulate; about nine of them occupy the space of a line. Abundant in the limestone of Keisley, near Dufton.

Remarks. This is probably the species referred to by Profs. Harkness and Nicholson * under the name of *Orthoceras vagans*, Salter. The present species differs, however, from the latter (as interpreted by Prof. Blake) in its more approximate septa, and in the well-defined character of the ornaments of the test, whereas Salter's species is described as smooth (Salter †) or showing only lines of growth (Blake ‡). All the specimens are more or less covered by the matrix, but the ornaments of the test are shown on several of them.

The present species differs from Portlock's in respect of the septa, which are wider apart than they are stated to be in his species. *Orthoceras sodale*, Barrande §, presents some resemblance to the present form in its slow rate of increase, the position of the siphuncle, and the surface-ornaments; but the septa are more remote in *O. sodale*, which is also a larger and more robust shell than the one here described.

There appears to be another species associated with this one in the same matrix, but it is too fragmentary for description.

2. Orthoceras, sp.

Description. An eroded fragment of a large *Orthoceras* from the *Staurocephalus* zone of Swindale is too imperfect for specific identification. The four chambers preceding the body-chamber are alone preserved. The shell may have been cylindrical or possibly elliptical in section; but the weathering it has been subjected to has destroyed its original form, causing one side to be flat while the other remains rounded. The septa are deeply concave; rather distant from each other, *i. e.* about seven lines apart where the diameter of the cast is about 1 inch 10 lines. The last two septa are, however,

* Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 461, 'On the Strata and their Fossil Contents between the Borrowdale Series of the North of England and the Coniston Flags.'

† In Sharpe, 'On the Geology of Oporto,' Quart. Journ. Geol. Soc. vol. v. (1849) p. 153.

‡ 'British Fossil Cephalopoda,' pt. i. (1882) p. 141.

§ 'Syst. Sil. de la Bohême,' vol. ii. pt. iii. (1874) p. 453, pl. ccccxvii. (excl. figs. 12, 13).

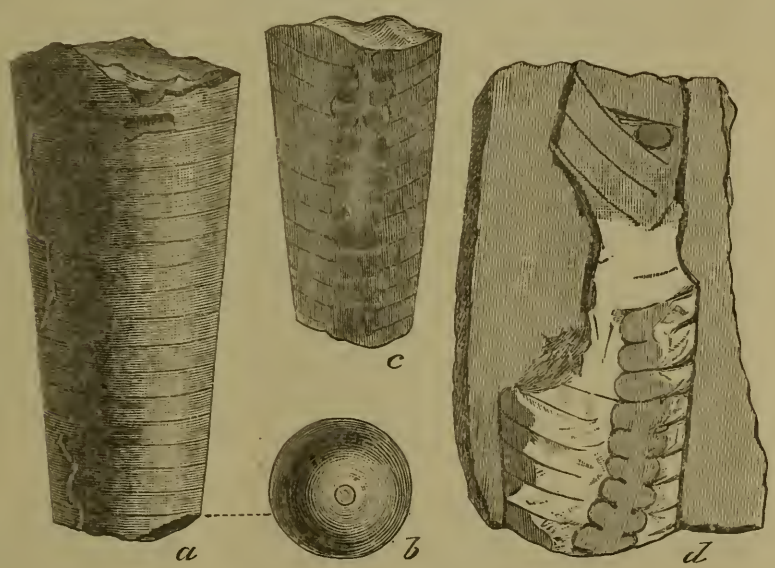
scarcely 6 lines apart, the diameter here having increased to about 2 inches. Two sections have been made, the one transverse, the other longitudinal, but without disclosing any trace of the siphuncle, which must have been contained in the part removed by weathering; if so, it could not have been far from the margin. No trace of the test exists.

Remarks. The general features of this fossil recall those of *Orthoceras ludense*, J. de C. Sow. (=*O. columnare*, Boll, *O. temperans*, Barr.), from the Upper Silurian rocks of Britain, Sweden, Bohemia, &c., and in its distant septa it is also comparable with *Orthoceras omissum*, Blake*. Both *O. ludense* and *O. omissum*, however, are found upon a much higher horizon than the present fossil.

3. Orthoceras pusgillense, sp. nov.

Description. Several fragments of the septate part of a species with a bulbous siphuncle were collected in the *Corona*-beds at

Orthoceras pusgillense.



a, cast, showing septa; *b*, base of septum with siphuncle; *c*, polished section; *d*, polished section, showing siphuncle pushed out of position.

Pusgill. The shell is cylindrical when uncompressed, and tapers somewhat rapidly, that is, at the rate of about 1 in $7\frac{1}{2}$, in a fragment 2 inches in length. The septa are very numerous, being about $1\frac{1}{2}$ lines distant from each other where the diameter of the shell is 11 lines; they are shallow, and are pierced by a nearly central siphuncle, having beaded segments which have a width equalling nearly one-fourth the diameter of the shell. The test is quite smooth. Some of the specimens have been crushed laterally

* 'British Fossil Cephalopoda,' pt. i. (1882) p. 160, pl. xv. figs. 9, 9 *a*.

in such a manner as to displace the siphuncle, bending it and forcing it towards the opposite side. No estimate can be made of the size of this fossil, the body-chamber being absent in all the specimens collected.

Three crushed and weathered fragments from the same locality and horizon, but somewhat larger than those just described, have similarly close-set septa and a beaded siphuncle, and they most probably belong to the same species.

The present form agrees with *Orthoceras* (? *Actinoceras*) *mendax*, Salter *, in the close proximity of its septa, but differs therefrom in its more rapid rate of tapering. The test not being preserved in the specimens from the Durness Limestone, upon which Salter's species was founded, no comparison can be made between the two species as regards this feature. It will be better therefore to regard it, provisionally, as new.

4. Cyrtoceras (?).

Fragmentary casts of the peripheral part of a small curved shell from Roman Fell exhibit septal characters similar to those of *Cyrtoceras* (*Phragmoceras*, Portl.) *inæquiseptum*, Portlock †, sp., from the Bala Beds of Desertcreat, Co. Tyrone. These specimens are too imperfect for description.

Discussion.

Prof. Boyd Dawkins said that the case cited by Mr. Marr of a fault having been in course of development at different geological periods is by no means an isolated example. Many faults show signs of movement at different ages. The Thousand-yards Fault, for example, passing up the valley of the Irwell to the N.W. of Manchester, shows a throw of 1000 yards in the Coal-measures, but very much less in the Permian and Triassic strata thrown down to the north. With regard to the phyllites, the phyllites of the Isle of Man form a link between the clay-slates on the one hand and mica-schist on the other.

Dr. Hicks asked whether the term "Bala," as used by the Authors, included any typical Llandeilo rocks; or whether it was confined, as he thought it ought to be, to such rocks as are classed under that name in North Wales. The section on the wall appeared to show a continuous succession from the Skiddaw Slates to Upper Silurian. He would be glad to know whether there was clear evidence of continuous deposition in the area generally; and whether there was no evidence of a break between the beds which had been recognized by Mr. Goodchild as of Tremadoc age and the overlying Arenig beds.

With regard to the faults shown on the map, he would like some explanation as to how the Authors accounted for the fact that they appeared repeatedly to cross the higher beds without affecting the

* Quart. Journ. Geol. Soc. vol. xv. (1859) p. 374, pl. xiii. fig. 24, *a*, *b*.

† 'Geology of Londonderry' (1843), p. 382, pl. xxviii. A. figs. 4 *a*, 4 *b*.

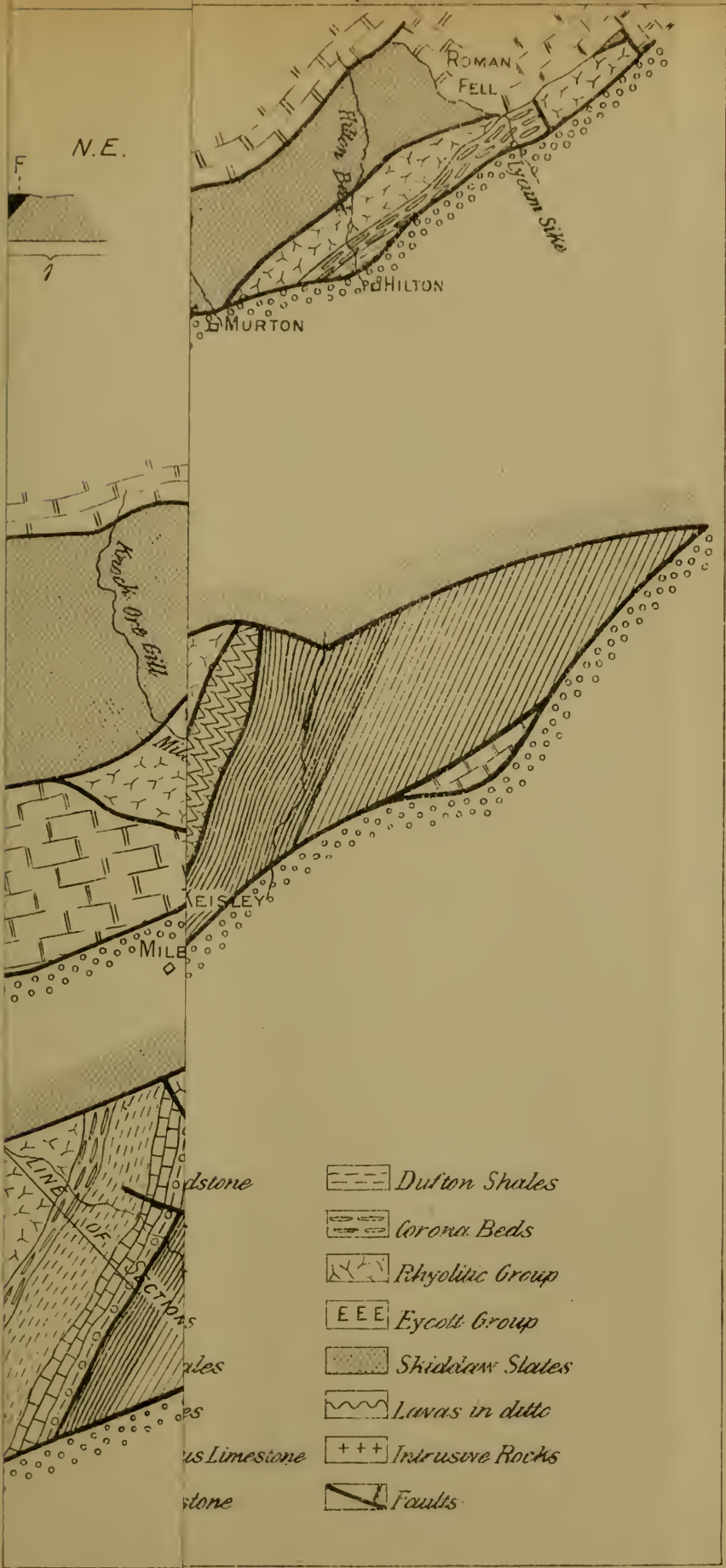
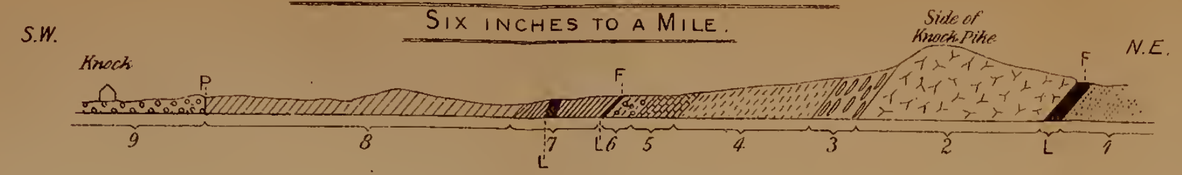

N.E.
F.
1
ROMAN FELL
Lycam Sike
P.H HILTON
MURTON
Knock Ore Gill
EISLEY
MILE
LINE OF SECTION
Dufton Shales
Corona Beds
Rhyolitic Group
Eycott Group
Skiddaw Slates
Lavas in ditto
Intrusive Rocks
Faults

Fig. 3. SECTION IN SWINDALE BECK

SIX INCHES TO A MILE.



1 *Skiddaw Slates*
2 *Rhyolitic Group*
3 *Corona Beds*
4 *Dufton Shales*
5 *Stauroccphalus Limestone*
6 *Ashgill Shales*
7 *Stockdale Shales*
8 *Coniston Flags*
9 *New Red Sandstone*
F *Faults*
P *Pennine Fault*
L *Lamprophyre*

Fig. I.

Fig. 2.

MAP OF THE CROSS FELL INLIER

ONE INCH TO A MILE.

(Fig. 2. is a portion of the same on the scale of two inches to a mile.)

underlying and adjoining older beds. He thought it would be well if the Authors could supply further evidence bearing on the direction of the earth-movements which had produced such results, and on the physical changes generally which had affected the area under discussion.

Mr. Rutley asked what was the breadth of the dykes represented in the section; and whether, in any case, they were found to follow the directions of faults. He approved of the application of the term "lamprophyre" to these rocks.

Mr. Hudleston said that the district was one of the most interesting from a geological point of view in England, and he expressed regret that so few persons who had been over the ground were at the meeting. It would have been an advantage to have heard Mr. Goodchild's views. Nevertheless, they had seen that it was possible to criticize effectually without special local knowledge. An intimate acquaintance with this Inlier would help to explain some of the difficulties experienced in the geology of the Lake District; the distribution of the Eycott-Hill type of rock was a case in point. There could be no better proof of the importance of the argument from palæontology than the correlation of the Dufton Shales with the Keisley Limestone, so unlike in lithological character. Perhaps the explanation of that difference as having been mainly due to subsequent deformation was open to some doubt. There could be no question as to the value and general interest of the paper.

The Chairman congratulated the Authors on the reception of their paper by the meeting, and pointed out that contributions of this class, in which stratigraphical details were illustrated by careful palæontological research, had become comparatively less common in the Society's Journal than they formerly were, although the value of such papers, as was well illustrated by the present example, had by no means diminished.

Mr. Marr, in reply, explained that the term "Bala" was used by them as synonymous with Caradoc, so that their Lower Bala of this district was not Llandeilo. He remarked that the apparent conformity between the Skiddaw Slates and the Rhyolitic Group was illusory, and that the newer beds abutted discordantly against the fault. He justified the absence of cross-faults in the Skiddaw Slates on the ground that the faults were only drawn where actually observed, but pointed out that Sedgwick had long ago shown how it was perfectly possible to get faults which did not affect older rocks in immediate vicinity to the newer rocks which were profoundly affected. He stated that Mr. Harker had in his appendix entered into some detail concerning the lamprophyres.

He observed that the Authors had not given any definite explanation of the difference between Keisley Limestone and Dufton Shales, as evidence for such was not to be gained from this isolated region. All that they maintained was that the Keisley Limestone and Dufton Shales were referable to the same subdivision, which was older than the *Staurocephalus*-Limestone and newer than the *Corona*-beds.